

**Water and Environmental Research Institute of the
Western Pacific
Annual Technical Report
FY 2017**

Introduction

The Water & Environmental Research Institute of the Western Pacific (WERI) is one of the 54 water research institutes established by U.S. Congressional legislation at each Land Grant University in the United States and its territories. Chartered in 1975, WERI is now in its 43rd year of operation.

Mission Statement: WERI's mission is to seek solutions through research, teaching, and outreach programs to improve exploration, production, distribution, and management of regional freshwater resources, with the ultimate aim of enhancing the prosperity and the quality of life for the citizens of Guam and the regional island nations.

Vision Statement: WERI maintains a faculty with expertise in each component of the natural water cycle and water resource management stream pertaining to the islands of Guam, FSM, and CNMI—from precipitation to coastal discharge, and from drinking water production to wastewater treatment. Research is strongly focused on local and regional needs, but also extends to basic research on topics of broader scientific interest. WERI leverages its local expertise by collaboration with the USGS Pacific Islands Water Science Center, with which it jointly administers a comprehensive hydrologic data collection program for Guam. WERI maintains laboratories staffed with expert technicians, and equipped for water quality analyses, GIS applications, field instrumentation, and database maintenance. WERI faculty support the University of Guam's graduate environmental science program and have lent crucial assistance to the establishment of the university's new School of Engineering. WERI recognizes that excellence in graduate instruction, deliberate recruitment, ample funding, and conscientious mentorship of talented graduate research assistants is fundamental to its success. WERI takes great pride in the success of the young scientists and professionals whose careers began under the guidance of its faculty. WERI faculty also provide vigorous programs for local professional development and school outreach in water resources education.

WERI's Federal Charter: WERI research and educational activities are sponsored by a variety of federal and local funding sources, but the institute was originally created to administer Department of Interior funds (via the US Geological Survey) under Section 104-B of the Water Resources Research Act. WERI has responsibility for three 104-B base grants: Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and the Federated States of Micronesia (FSM). This report summarizes WERI's regional activities under the USGS 104-B base grant program for the period March 1, 2017 to February 28, 2018 (FY2017).

WERI's Local Mandates: Since 1998, WERI has also administered two locally-funded programs: the Guam Comprehensive Water Monitoring Program (CWMP), established under Guam Public Law 24-161, and the Guam Hydrologic Survey Program (GHS), established under Guam Public Law 24-247. These programs provide for island-wide hydrologic data collection and analysis in partnership with the USGS Pacific Island Water Science Center in Honolulu, Hawaii, through the USGS Groundwater and Streamflow Information Program. The data, along with other basic and historical data are maintained in the Northern Guam Lens Aquifer Database, which is the foundation for WERI's aquifer mapping and groundwater modeling programs. With the information and understanding gained from these programs, WERI provides technical support services, including annual workshops and field trips, for Guam's public and private sector water resources professionals.

Staffing: WERI is led by a full-time director appointed from among its faculty for three years at a time. The director's office is supported by a secretary and administrative assistant. WERI has six permanent faculty and two emeritus faculty. Its water quality laboratory is staffed by a laboratory manager, chemist, and technician. The CWMP and GHS programs are managed by WERI's groundwater hydrologist with the assistance of a Ph.D. research associate. WERI researchers also support full-time graduate research assistants who are completing their MS degrees in the UOG Environmental Science program.

WERI's Research and Teaching Activities: Expertise at WERI spans the natural water cycle and the spectrum of human water use. Research specialties and graduate instruction include tropical meteorology, surface water hydrology, groundwater hydrology, wastewater treatment, water quality, and the application of geospatial analysis to water resources problems. In support of these activities, WERI operates a state-of-the-art water analytical laboratory and a geographical information systems laboratory. WERI faculty contribute to graduate instruction and student thesis research within the university's Environmental Science and Biology programs. WERI is also making a central contribution to the launching of the university's new School of Engineering by assisting with student advisement, faculty recruitment, facilities planning, and liaison with the local professional community and with regional and stateside partner universities.

Research, Teaching, and Professional Output: During FY2017, WERI faculty served as principal investigators and/or advisors on more than twenty research, training, and outreach activities with a total budget of approximately \$1.5M. During the reporting period, WERI faculty taught 13 graduate courses in the University of Guam's Environmental Science program. WERI faculty chaired 13 thesis committees of students in the Environmental Science and Biology MS programs and served on 11 other committees. During this time WERI faculty also published three refereed journal articles, seven technical reports, four conference proceedings papers, and gave twenty-one professional presentations.

Other Funding Sources: Funding sources in addition to the US Geological Survey, include the National Oceanic and Atmospheric Administration, the National Weather Service, the National Science Foundation, USGS Pacific Islands Climate Science Center, the US Department of Defense, and local agencies including the Guam Legislature, Guam Waterworks Authority, Guam Bureau of Statistics and Plans, and the Guam Environmental Protection Agency. Private funding was provided by the Ford Motor Company's Global Giving Foundation for educational outreach on water conservation. Some specific projects are listed below, by funding source:

Guam Legislature: 1) The Guam Comprehensive Water Monitoring Program, which provides Guam's share of funding for the USGS Groundwater and Streamflow Information Program with USGS Pacific Islands Water Science Center, Honolulu, Hawaii 2) The Guam Hydrologic Survey (GHS), which in turn is funding the following projects: a) Annual trend reporting, and maintenance of the GHS/WERI database b) Exploring the Northern Guam Lens Aquifer limits with a 3-D groundwater model c) Workshop series on Guam groundwater resources d) Lessons learned from ongoing production-well installation and rehabilitation e) GIS-based imagery database for groundwater recharge and streamflow on Guam f) Tracking the history of freshwater storage in the Northern Guam Lens Aquifer g) Chloride trends in the Yigo-Tumon Basin, Northern Guam Lens Aquifer h) Sinkhole atlas of northern Guam i) Investigation of landslide threat to southern Guam watersheds

Guam Bureau of Statistics And Plans: 1) Developing Hydrological Data for Toguan Watershed Management

Guam Waterworks Authority: 1) Developing Hydrological Data for Toguan Watershed Management 2) Santa Rita Spring Rehabilitation 3) Northern Guam Lens Aquifer Monitoring System Expansion and Rehabilitation

National Science Foundation: 1) Hydrochemical Processes Control Weathering in the Unburied Karst Landscapes

National Oceanic And Atmospheric Administration: 1) Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Climate Forecast & Information

Research Program Introduction

WERI has three community advisory councils that provide stakeholder advice and assistance for setting research goals and priorities for the USGS 104-B program along with WERI's other research, education, and outreach programs. The Guam Advisory Council includes representatives from local and federal civil agencies and military environmental and engineering offices that deal with water resources issues, as well as colleagues in the university research community. The advisory councils for the Commonwealth of the Northern Mariana Islands (CNMI) and the Federated States of Micronesia (FSM) include representatives from government departments that deal with water resources, private sector professionals, environmental regulators, faculty from the local colleges, and other University of Guam research faculty who work on these islands. The advisory councils identify and advise on research and training needs for each region. WERI maintains a list of each region's needs, which is updated after each annual meeting.

The advisory council meetings for FY 2017 were held in September through November 2017. In early December, the WERI faculty updated its WERI Research, Education, and Outreach Agenda (<http://www.guamhydrologicsurvey.com/index.php/weri-2017-research-education-and-outreach-agenda/>) based on needs and opportunities identified and discussed in the advisory council meetings. Principal investigators were advised and encouraged to develop and pursue multi-year (three-to-five-year) collaborative projects based on the updated agenda involving other faculty members at the University of Guam and other institutions, including the Northern Marianas College in Saipan, and the College of Micronesia in Pohnpei, and water resource professionals from local and federal government agencies in the region.

Based on the 2017 update to the research agenda derived from the advisory council meetings, the WERI faculty, in consultation with the WERI director, agreed upon five research projects and five information transfer projects funded with 104-B program funds. These projects are described in detail in the rest of this report.

Expansion of N-baseline data in the Northern Guam Lens Aquifer

Basic Information

Title:	Expansion of N-baseline data in the Northern Guam Lens Aquifer
Project Number:	2017GU309B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Categories:	Nitrate Contamination, Groundwater, None
Descriptors:	None
Principal Investigators:	Nathan C Habana, Joe Rouse, John W. Jenson

Publications

1. Habana, Nathan, Joseph Rouse, John Jenson, 2017, Expansion of Baseline Data for the Northern Guam Lens Aquifer and Evaluation of Innovative Technologies to Reduce Contaminant Input, Guam Hydrologic Survey Workshop, GHS Workshop, WERI, UOG, Mangilao, Guam.
2. Habana, Nathan, Joseph Rouse, John Jenson, 2017, Expansion of Baseline Data for the Northern Guam Lens Aquifer and Evaluation of Innovative Technologies to Reduce Contaminant Input, WERI Annual Guam Advisory Council Meeting, Tumon, Guam.

PROJECT SYNOPSIS REPORT

Project Title: Expansion of N-baseline Data in the Northern Guam Lens Aquifer.

Problem and Research Objectives

The Northern Guam Lens Aquifer (NGLA) is Guam's primary source of freshwater for potable use. This porous limestone formation currently provides approximately 80% of the island's municipal water supply. Aggressive production of groundwater has grown to 40 million gallons per day (mgd). With water demand rising and concerns over water quality increasing, proper management of this freshwater source has become critical to the welfare of the island's increasing population of residents and tourists. Preliminary inquiries have suggested that contaminants from anthropogenic sources are showing up in the NGLA. Much more baseline data of contaminant concentrations are needed to determine if the problem is greater in zones with sewer collection lines or in zones that rely on household septic tanks; furthermore, it is not known if contaminant levels are increasing, or not. It is essential that these issues be studied before actions are taken to extend sewer collection lines or even build new wastewater treatment plants in Northern Guam. In addition, the effectiveness of septic tanks is also an issue of concern. Septic tanks are not known to provide much treatment, other than the removal of readily settleable suspended solids, and it is not known how many of the existing tanks are even discharging to adjoining tile fields as intended. It is through the process of percolating evenly over the tile field that the actual reduction in contaminant loadings via natural processes is meant to occur.

As an alternative to traditional septic tanks, consideration is increasingly given to use of single-family prefabricated packaged treatment units. These units have the potential to achieve secondary to advance levels of treatment, and as such could serve to greatly reduce the potential of contamination reaching the NGLA.

The objective of this research is to conduct research on spatial and temporal trends in levels of contaminants in Guam's groundwater. This includes the need to expand upon baseline studies of levels of nitrogenous compounds, etc. with respect to time and location. In addition, it addresses the need for pilot studies of innovative wastewater treatment units as alternatives to conventional septic tanks for individual homes.

The project will produce a report that offers further enlightenment as to the transport and fate of contaminants of anthropogenic sources in the sub-surface, and anticipated trends for the near future. These results will strengthen modeling capabilities addressing the water quality of the NGLA, thus being of importance to human safety.

Methodology

Data collection was first done on selected production wells having a history of more than 4 mg/L Nitrates. WERI Technical Report #95 has a map of wells of nitrate trend analysis. Selection criteria include production wells near sewer areas, non-sewered areas, and a combination of both sewer and non-sewered. Multi-probe testing units with logger (YSI Inc., Professional Plus) had been installed at selected sites to measure N-nitrate, N-ammonium, DO, temperature, atmospheric pressure, and electrical conductivity, continuously on an hourly basis. However, as was quickly learned, the need for frequent calibration of the probes made it ineffective to work in a continuous mode. Thus, it was deemed most efficient to visit testing sites with hand-held units to conduct analyses on a weekly basis.

Principal Findings and Significance

Preliminary and on-going inquiries have suggested that contaminants from anthropogenic sources are showing up in the NGLA. From the data obtained here it is not evident that ammonium and nitrate levels in the environment are changing with time. Results do show, though, that ammonium is nearly absent (always less than 1 mg N/L) in the groundwater, indicating that biologically induced nitrification is occurring in the environment. The presence of low levels of nitrate (ca. 3 to 5 mg N/L) corroborate this, though there is no indication yet that denitrification is contributing to reduction of nitrate levels, versus only dilution. It is essential that these issues be further studied before actions are taken to extend sewer collection lines or even build new wastewater plants in Northern Guam. In addition, the effectiveness of septic tanks is also an issue of concern. As an alternative to traditional septic tanks, consideration is increasingly given to use of single-family prefabricated, packaged treatment units. These units would serve to reduce the potential of contamination reaching the water table. From data obtained in Yigo during this testing period, test results of effluent from a prefab-unit yielded chemical oxygen demand (COD) of 105 mg COD/L as compared to effluent from a conventional septic tank of 268 mg COD/L. The prefab-unit tested here, though, was intentionally not properly serviced, i.e., standard maintenance and cleaning had not been performed over a couple of years. Thus, further comparative testing is to be conducted following proper maintenance to determine a more realistic potential.

Exploring the natural limits of the Northern Guam Lens Aquifer: Phase 4 – model implementation, determining ultimate yield in basal and parabasal zones

Basic Information

Title:	Exploring the natural limits of the Northern Guam Lens Aquifer: Phase 4 – model implementation, determining ultimate yield in basal and parabasal zones
Project Number:	2017GU310B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Categories:	Groundwater, Hydrology, Water Quantity
Descriptors:	None
Principal Investigators:	Nathan C Habana, John W. Jenson

Publications

1. Habana, Nathan, John Jenson, Stephen Gingerich, 2017, Evaluating Best-Practice Capacities for a Carbonate Island Karst Aquifer: Northern Guam Lens Aquifer, Guam, USA, Karst Hydrology session - NGWA Groundwater Summit, December 4-7, 2017, NGWA, Nashville, Tennessee.
2. Superales, Daniel, Nathan C. Habana, Barry Kim, John Jenson, Stephen Gingerich, 2017, NGLA Groundwater Model Explorations, Guam Advisory Council Meeting, November 9, 2017, Tumon, Guam.
3. Superales, Daniel, Nathan C. Habana, Barry Kim, John Jenson, Stephen Gingerich, 2017, NGLA Groundwater Model Explorations, Guam Hydrologic Survey Workshop September 11 & 18, 2017, Mangilao, Guam.

PROJECT SYNOPSIS REPORT

Project Title: Exploring the natural limits of the Northern Guam Lens Aquifer: A step toward optimum sustainable management, Phase 4 – model implementation, determining ultimate yield in basal and parabasal zones

Problem and Research Objectives

The Northern Guam Lens Aquifer (NGLA) provides 90% of Guam's drinking water. The anticipated addition of US Marine Corps activities will require additional production, while ongoing economic growth will increase demand as well. Policy-makers and water managers have begun asking "what is the absolute *maximum* volume of water that could be sustainably withdrawn from the aquifer?" Answering such a question requires identifying (1) the *natural limits* on aquifer recharge, storage, and water quality imposed by climatic and geologic conditions, (2) , but doing it *for an ideal production system*, i.e., one that is constructed and operated so as to achieve the maximum possible production for a given standard of quality. This study is therefore directed at estimating the *maximum potential capacity* of the NGLA, i.e., the capacity that ultimately *could* be achieved by an ideal production system, given what we currently know or must assume about the natural limiting conditions. Recent modeling has incorporated the current state of knowledge regarding natural conditions and constraints. The third phase model simulated maximum yield in the optimum boundary, less susceptible to saltwater up-draw, the parabasal zone. In the this fourth phase, estimates of maximum potential capacity can now be made by exploring scenarios in which hypothetical well depths, expansion by addition of basal wells, and pumping rates are distributed so as to maximize the capacity for given upper limits of chloride. This study will thus help provide some estimates of the absolute upper limits of production that could, in principle, be achieved by an optimum system. These will provide ultimate baselines against which to make economic evaluations of future options for holistic sustainable management of the aquifer.

Objectives: The objectives of the respective phases of this project are:

- (1) Data acquisition and literature review of published and emerging research on spatial and temporal distributions and trends of rainfall and salinity in the NGLA by WERI, USGS and others;
- (2) Study of meteorological and geological phenomena that might control or influence the observed rates and amounts of rainfall, infiltration, storage, flow, and salinity; and
- (3) Analyses of spatial and time-series data on rainfall, groundwater levels, specific conductivity, chloride concentrations, and production rates from existing wells within the NGLA; and
- (4) Application of a groundwater model to estimate the maximum production that could be attained from an optimum set of strategically spaced shallow-draft vertical wells producing at specified maximum acceptable values of salinity, under specified natural conditions (*e.g.*, long-term average rainfall, vs. historic wet and drought conditions)

Development of a production function that estimates the relationships between quantity and quality that might be produced by an ideal production system (i.e., one that would produce maximum quantity for a given quality or maximum quality for a given quantity).

Methodology

The principal investigators led a research team composed of themselves and WERI-based student research assistant, working in collaboration with colleagues at the USGS Pacific Islands Water Science Center (PIWSC). The modeling plan was to take the previous parabasal production model of 130 wells (Phase 3), setting all of the wells pump rates to 222 gpm (2013 NGLA production rate average), and bottom of all wells to the limit depth of -40 feet below msl (Guam EPA regulations). Production wells in the simulation that produced chloride concentrations above 250 mg/L (USEPA regulations) were relocated and the model reran through several simulations until they were all below the regulations. For the same spatial configuration of wells of the last successful simulation, the pump rates of all the wells were increased to 500 gpm. The 222 gpm and 500 gpm simulations were compared and contrasted to the real system of 2013. The Aquifer basins also compared pump rate weighted average chlorides in each aquifer basin.

Principal Findings and Significance

The 222 gpm and 500 gpm simulations were compared and contrasted to the real system of situation 2013. At 222 gpm, total and aquifer basin averages were less than 72 mg/L, where the high aquifer basin average is of the Hagåtña Basin. At 500 gpm, total aquifer basin average is 443 mg/L, and the basin average high was again Hagåtña Basin. The basic idea was to show that parabasal wells are a major improvement compared to the existing system, where total average is 319 mg/L and high basin average of 623 (Hagåtña). Findings also led to the idea that there could be simulations for other rates and chloride concentrations for each well, at each basin, and for the entire aquifer. The next phase will examine pump rates, from 100 gpm, incrementing in 50 gpm to 500 gpm. The significance is a step towards graphically displaying sustainable yields at the parabasal zone.

PFOS Trend Monitoring in a Guam Drinking Water Production Well

Basic Information

Title:	PFOS Trend Monitoring in a Guam Drinking Water Production Well
Project Number:	2017GU313B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Categories:	Water Quality, Groundwater, Toxic Substances
Descriptors:	None
Principal Investigators:	Gary Denton, John W. Jenson, Mark Lander, Carmen M SianDenton

Publication

1. Denton, G.R.W., Carmen M. Sian Denton, Young S. Kim, John W. Jenson, Nathan C. Habana, Mark L. Lander, 2018, Perfluorooctane Sulfonate (PFOS): A Contaminant of Emerging Concern in Guam's Groundwater (Abstract), The IRES - 415 International Conference on Engineering and Natural Sciences, (ICENS) , June 29-30, 2018, Beijing, China.

PROJECT SYNOPSIS REPORT

Project Title: PFOS Trend Monitoring in a Guam Drinking Water Production Well.

Problem and Research Objectives:

Perfluorooctane sulfonate (PFOS) or perfluorooctane sulfonic acid, as it is otherwise known ($C_8F_{17}SO_3H$), is one of a large family of fluorinated aliphatic compounds that have been widely used in industry over the past 60 years (Buck *et al.* 2011). Historically, PFOS has been extensively used in the manufacture of water-proof apparel, stain-resistant carpeting, upholstery and leather goods, oil and grease-proof cardboard and paper products, various industrial and household cleaning agents, cookware coatings and coating additives, fire-fighting foams, and in insecticide applications and oil drilling (Carloni 2009, Lim *et al.* 2011, Zhang *et al.* 2012).

PFOS is of interest to environmental regulators because it is highly persistent and has substantial bioaccumulation and biomagnification properties, particularly in humans. It is also moderately water soluble (~600 mg/L) and has recently emerged as a drinking water contaminant of potential concern, having so far been detected in approximately 2% of public water systems across the Nation (Hue *et al.* 2016). In 2009, USEPA issued a provisional drinking water health advisory (HA) for PFOS of 200 ng/L. A final HA of 70 ng/L was promulgated in May 25, 2016 (Federal Register 2016).

The Guam Waterworks Authority (GWA) began monitoring PFOS in Guam's groundwater in March 2015, in response to USEPA's third *Unregulated Contaminant Monitoring Rule*, (UCMR3) (USEPA 2012). Overall, five production wells were identified as PFOS contaminated (Fig. 1) and levels in two of them (A-23 and A-25) were consistently above the USEPA's 70 ng/L benchmark. Both wells are taken offline in 2016. WERI and GWA have subsequently embarked on a collaborative project to continue monitoring the most contaminated well (A-25)

The primary objectives of the study were to identify: a) seasonal fluctuations in PFOS concentrations within well A-25 and any relationships between these levels and local precipitation rates; b) any long-term temporal trends in PFOS levels within the well that suggest concentrations in the underlying aquifer are increasing, have stabilized, or are

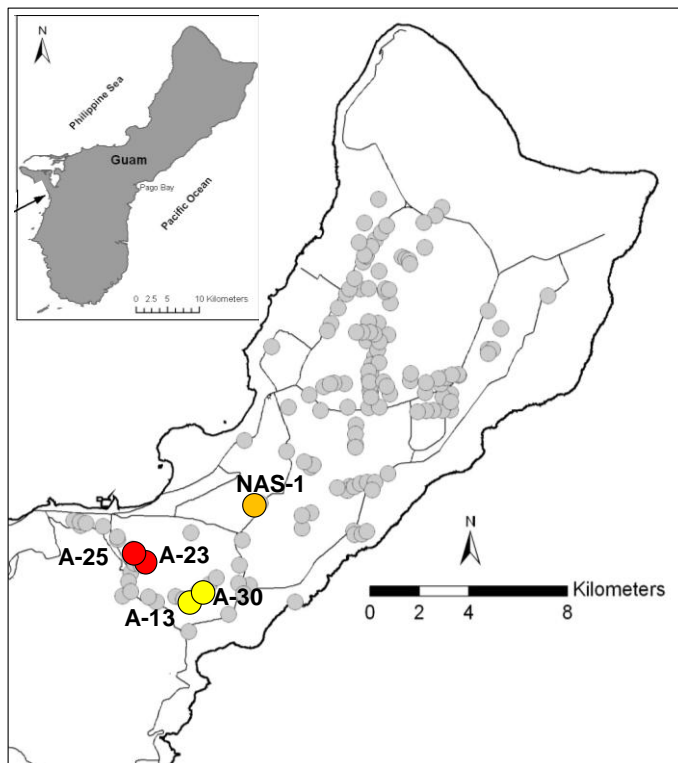


Figure 1: GWA production wells in northern Guam with PFOS detections. Red and yellow circles = wells with PFOS levels consistently above and below 70 ng/L respectively. Orange circle indicates one exceedance to date.

attenuating; c) potential primary sources of PFOS and their possible locations within the watershed and beyond the study area; and d) the most practical and cost-effective management strategies for resolving this issue in order to get both wells back on line.

Methodology:

Daily rainfall measurements for years 2015-2018, were obtained from the Guam NOAA Weather Forecast Office website (<http://www.prh.noaa.gov/guam/>). The data were collected at the Guam International Airport meteorological station on the central western side of the island. The linear distance between the station and the center of the Agana-Chaot River Basin is about 4 km.

Monthly sampling of well A-25 began in June 2017 and is ongoing. Prior to each sampling event, the well was brought back on line and run to waste to flush any residual PFOS contamination remaining in the plumbing. Subsequently, all samples were collected in 250-ml polypropylene bottles (Nalgene) and immediately cooled on ice before same-day shipping to *Eurofins Eaton Analytical* (Monrovia, California, USA) for analysis. This laboratory is certified to test for all regulated and non-regulated chemicals listed under the Safe Drinking Water Act.

Principal Findings and Significance:

Mean annual rainfall on Guam is about 100 inches and can be considerably higher in El Niño years, when tropical storms and typhoons are more prevalent. The monthly rainfall data shown in Figure 2 illustrate the rainfall disparities within and between months for the years in which PFOS determinations have been made on Guam, including GWA's earlier data. It is noteworthy that 2015 was an epic El Niño year, delivering 104 inches of rain to the island. In contrast, 2016 was a post El Niño year and brought drought conditions to the island for the first half of the year and near record rains for the remainder. Year 2017 was considered a weak La Niño year as is the current year. Total rainfall for both years was 94 and 97 inches, respectively. Total rainfall for January and February of the current year has been unusually low.

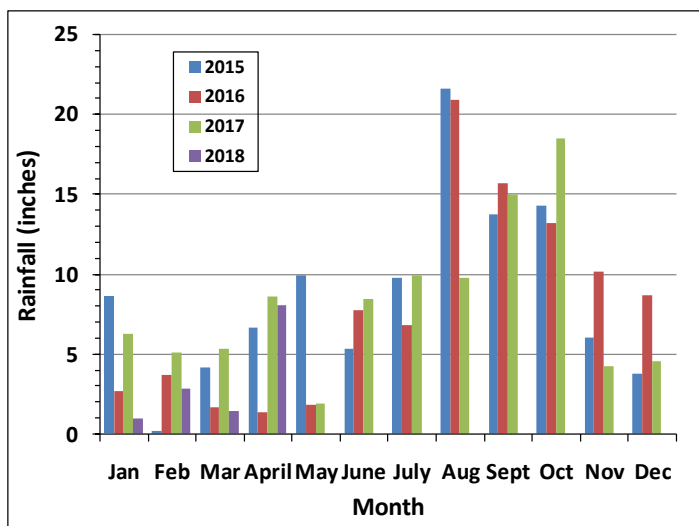


Figure 2: Monthly rainfall values taken at Guam International Airport for years 2015-2017 and 2018 (January-April only)

Monthly PFOS values determined in groundwater samples from well A-25 are presented in Table 1 together with cumulative precipitation recorded 30, 60, 90 and 120 days immediately prior to each sampling event. The 2015-16 PFOS data obtained by GWA are also included for comparative purposes. Second order polynomial regression analysis gave the best fit line to all PFOS-rainfall data plots. Coefficients of determination (R^2) comparisons were used to approximate the response time of well A-25 to episodic releases of PFOS into the aquifer. A weak association was noted between PFOS and the 30-day cumulative rainfall data ($R^2 = 0.313$).

The relationship strengthened appreciably with the 60-day and 90-day datasets ($R^2 = 0.801$ and 0.842 respectively), and weakened thereafter (Fig. 3).

Table 1: PFOS in well A-25 and cumulative rainfall data prior to each sampling event

Collection Date	PFOS (ng/L)	Total Rainfall Prior to Sampling (inches)			
		30 Days	60 Days	90 Days	120 Days
26-Mar-15	220	3.47	4.17	13.5	16.3
28-Sep-15	410	13.7	35.1	45.0	50.0
11-Aug-16	220	16.9	24.7	27.9	29.6
08-Jun-17	210	2.81	10.9	16.0	18.9
24-Aug-17	260	12.2	20.1	25.8	28.2
28-Sep-17	340	14.1	27.0	33.4	41.8
30-Oct-17	360	19.6	33.5	43.1	52.7
11-Dec-17	260	4.60	19.6	32.4	46.8
22-Jan-18	270	1.55	6.20	10.0	29.5
12-Mar-18	240	2.07	3.93	6.16	10.7

From these initial findings it was tentatively concluded that episodic inputs of PFOS into the study area take about a month to reach well A-25. Variations in the duration and intensity of rain events over the preceding month seem to have the greatest influence on this estimate.

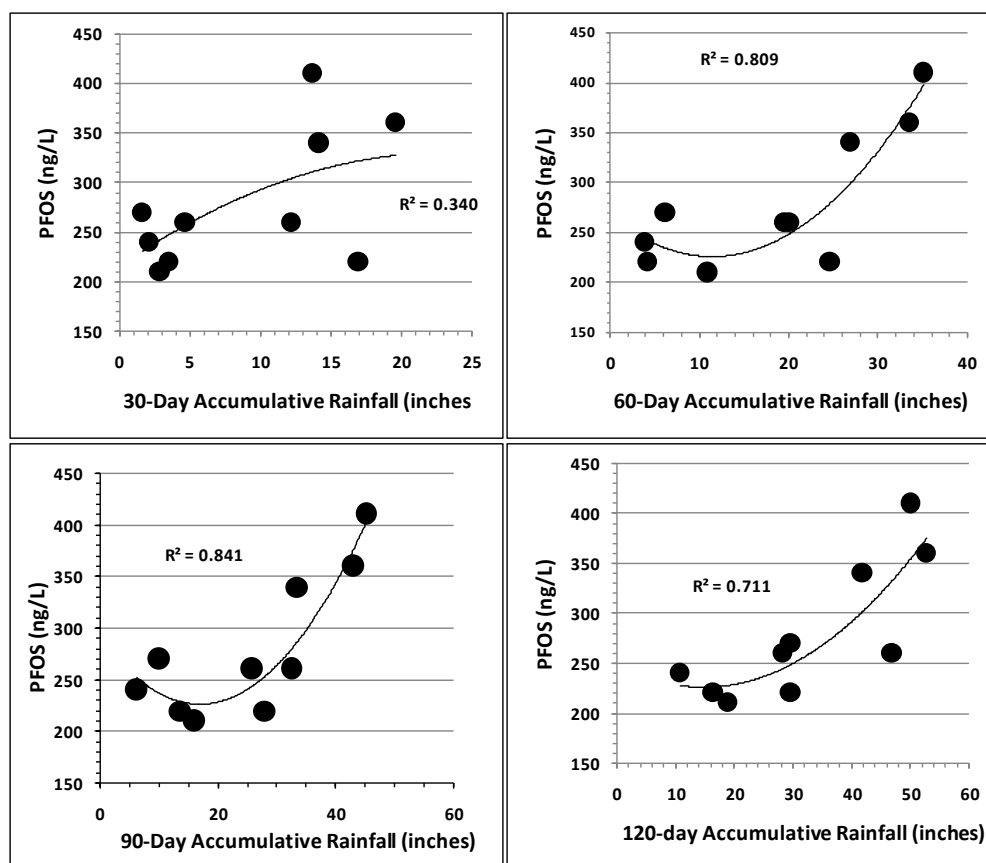


Figure 3: PFOS levels in well A-25 vs. cumulative rainfall prior to each sampling event. Trend line fitted to the data using a second order polynomial regression model.

As of this writing, there have been no major rains over the study area since the second week of October 2017. Total rainfalls recorded in November and December of 2017, and in January of 2018, were 4.23, 4.49, and 0.94 inches, respectively. Since rainfall provides the only means of transporting PFOS from its land-based source into the region of the aquifer that serves well A-25, the lower PFOS levels noted in the December 2017 and January 2018 samples were not surprising. Presumably, the leveling off of PFOS to around 260 ng/L (Table 1) coincides with little to no water movement through the aquifer and takes about a month to occur once monthly rainfall drops to around five inches or less. At this point, the default 'baseline' PFOS concentration lies somewhere between 200 and 250 ng/L (Fig. 3).

In light of these findings, any further PFOS attenuation in well A-25 seems unlikely unless the major source or sources of contamination impacting the watershed are identified and removed.

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Composting waste sludge in Yap, FSM

Basic Information

Title:	Composting waste sludge in Yap, FSM
Project Number:	2017GU314B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Categories:	Conservation, Management and Planning, Treatment
Descriptors:	None
Principal Investigators:	Joe Rouse, Hyun-Jong Hahm

Publications

1. Rouse, Joseph D., Hyun Jong Hahm, 2018 “Improvements to Sewage and Sludge Treatment Operations on the Island of Yap, FSM.” 2018 Pacific Water Conference – Enhancing Hawai’i’s Water Environment. Hawai’i Water Environment Association & American Water Works Association. Honolulu, Hawaii; February 7-8, 2018.
2. Rouse, Joseph D., Hyun Jong Hahm, 2018 “Developing public awareness of benefits of composting waste sludge in Yap.” Island Sustainability Conference: Island Alliance for Sustainable Action. University of Guam, Center for Island Sustainability. Tumon, Guam; March 27-30, 2018.

PROJECT SYNOPSIS REPORT

Project Title: Composting Waste Sludge in Yap, FSM

Problem and Research Objectives

On Yap Island in the Federated States of Micronesia (FSM) the centralized sewage treatment plant (STP) consists of an Imhoff tank system, which by design provides little more wastewater treatment than removal of easily settleable solid material. The organic material (sludge) that is collected is held in an underlying tank where some degree of digestion occurs. On a quarterly basis, the partially digested sludge is drawn and placed on a sand-drying bed, from which it is to be air dried and then deposited in the local solid-waste landfill. However, before the material can be transported or treated, local farmers are known to always take the material and use it as a fertilizer or soil conditioner for production of food crops.

In keeping with international standards, there are treatment procedures that can be followed to render the waste sludge suitable for public use. Composting is one such option that can be considered as an environmentally friendly method to recycle the nutrients and organic matter found in the waste sludge. In FY 2015-2016, pilot testing was conducted at the STP to demonstrate composting techniques suitable for treatment of the air-dried sludge involving mixing with green waste using grass cuttings on the plant grounds (WERI Technical Report 161). From those results, it was clear that one of the unused drying beds could easily be converted and put to use as a compost row with minimal in-house effort.

The objectives of the proposed project are to implement a composting facility to make use of the waste sludge, rather than sending it to the landfill, and to promote public awareness of the project's potential benefits.

Methodology

The methods employed over the course of this project incorporated civil engineering fieldwork and standard laboratory analyses. The work was carried out under the supervision of the PIs and the Manager of the Water and Wastewater Division, YSPSC, with the cooperation of the Director of the Yap-EPA.

For the composting facility, a simple wooden frame was constructed and fitted with a plastic awning. For operating procedures, guidance was followed from proven references (including WERI Technical Report 161) to determine the best mix ratio of grass cuttings to dried sludge and the turning/mixing frequency. Industrial thermometers were used to monitor the temperature of the compost piles. The Yap EPA assisted with monitoring of pathogens (*E. coli* and total coliform), which

required adapting their liquid-based method for use with solid sludge and the composted product.

Principal Findings and Significance

These objectives of this research were met by construction of composting bins made of locally purchased materials, teaching the proper operating methods, and establishing the protocol for monitoring the quality of the compost produced at the facility. Furthermore, channels of communication were established to educate public officials and the general public.

The final facility consisted of 10 bins over a 60-ft row (see photo). The work was done relying solely on the local staff of the Yap State Public Service Corporation and was completed during a one-week period within the originally estimated budget.



By employing composting for treatment of the waste sludge, it should be possible to produce an exceptional quality (Class A sludge product by U.S. EPA standards) biosolids product without any crop harvesting restrictions. However, such a product would have to be tested (by readably available methods) to confirm the pathogen count. Depending on the level of treatment achieved, the cured compost could be used for production of food crops, or for environmental reparation of badlands if the treatment level is not adequate for direct human exposure. In addition, reuse of this waste product will reduce the demand for valuable land as required for the landfill, which is especially a concern on an island, where land is of a premium.

The first round of loading and composting the sludge was completed by the end of the USGS annual cycle. Results were good, though, it did take about two months to convert the compost product to a safe, usable product, with *E. coli* counts down to

zero to one organism per gram of composted product in most bins. Under ideal conditions, it would be thought that about only one month should be required. One concern was that the compost material only reached 120 F, while most standards state that 130 F (over about one week during the process) is required to properly pasteurize the material. Potential reasons for this less-than-ideal outcome have been discussed and plans for optimization will be implemented during the following year of operation (as a subsequent USGS project – underway now). In the meantime, the general public have been notified and have been stopping by with their pickup trucks to get their share for either crop application for non-crop use, as appropriate for the quality of the compost that is available.

Public awareness of the project's objectives were initiated by communication with various state government offices (e.g., Resources & Development, Agriculture and Forestry, EPA, etc.) and these venues will be further pursued during the next phase of the project. Educational factors to be considered will include instruction on the dangers of handling inadequately treated sludge-based products and also the potential benefits to be derived from this valuable resource. In addition, easy to understand signage will be implemented to assist with operations at the facility.

Impact of Stormwater from a Constructed Wetland in American Memorial Park, Saipan, CNMI, on Receiving Waters and Fisheries Resources

Basic Information

Title:	Impact of Stormwater from a Constructed Wetland in American Memorial Park, Saipan, CNMI, on Receiving Waters and Fisheries Resources
Project Number:	2017GU316B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Categories:	Toxic Substances, Water Quality, Non Point Pollution
Descriptors:	None
Principal Investigators:	Gary Denton

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Title: Impact of Stormwater from a Constructed Wetland in American Memorial Park, Saipan, CNMI, on Receiving Waters and Fisheries Resources.

Problem and Research Objectives:

The American Memorial Park (AMME) in Saipan is a 54 ha parcel of land that borders the central region of a large lagoon on the western side of the island (Fig. 1). It was constructed in 1978 under the administrative control of the US National Park Service (NPS) to commemorate US soldiers killed during the Saipan invasion. Located in the village of Garapan, the land upon which the park now sits was occupied by the US Navy immediately after the WWII and aerial photographs taken in 1948 reveal military buildings scattered over much of the property. The area served primarily as a motor pool and maintenance and repair facility back then, as well as a refueling station for military and civilian personnel (Ogden 1998). Allotments were also set aside for the stockpiling and disposal of residual munitions and other hazardous materials (AMPRO 2005). The indiscriminate dumping of garbage on the property was commonplace and continued until well into the 1970s (Raulerson 1989).

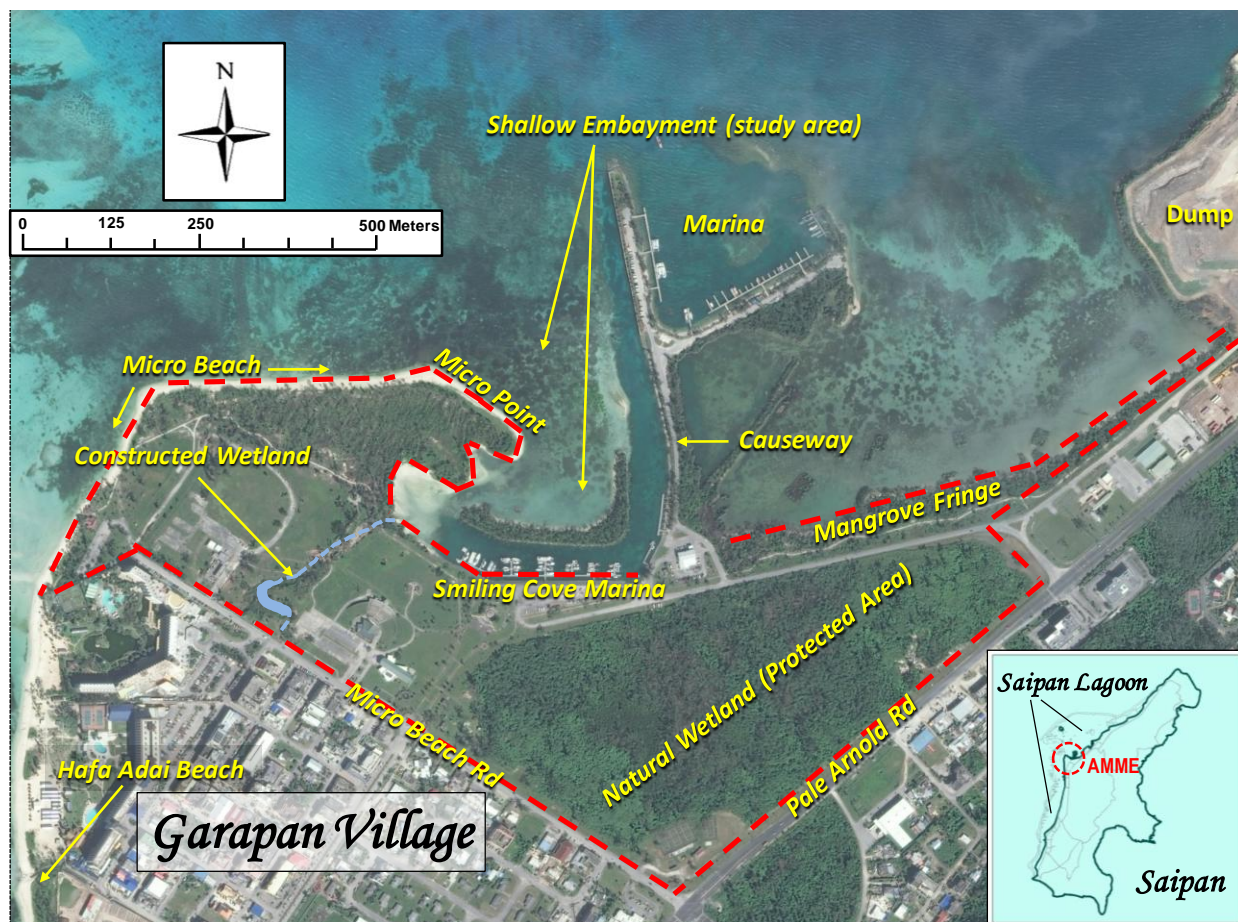


Figure 1: Map of Saipan (inset) showing location of American Memorial Park (AMME) in Garapan Village. Dashed red line on main map indicates AMME boundary.

In the 1990, as part of flood mitigation plan for Garapan village, an artificial wetland was created in the northwest section of the park to redirect stormwater from the main business center into the ocean. The wetland is essentially a crescent-shaped pond that drains into the coastal belt immediately west of *Smiling Cove Marina* (Fig. 1). The receiving waters are confined to a shallow water embayment that is partially enclosed by land and land-based structures. Despite water movement within the embayment being relatively restricted, the area supports a thriving seagrass community and is popular fishing spot among local residents.

While mercury is rarely detected in urban runoff (USEPA 1983), much of Garapan was subjected to mercury fallout from a nearby medical waste incinerator that operated for over 20 years before it was shut down in 2006 for violations of the Clean Air Act (USEPA 2005). Mercury emissions from this facility were previously shown to have elevated mercury levels in fish from central Garapan coastal waters as a result of contaminated runoff (Denton *et al.* 2011a and b). Bottom deposits from within wetland itself were also found to be moderately mercury enriched at the time, with maximum levels ranging from 50-75 ng/g dry weight. Baseline mercury levels in Saipan soils are generally around 30 ng/g and rarely exceed 50 ng/g (Denton *et al.* 2016).

Soils throughout AMME also carry a mercury footprint associated with the detonation and disposal of residual munitions on the property immediately after WWII (AMPRO 2005, Denton *et al.* 2018a). This is believed to reflect the widespread use of fulminated mercury in WWII munitions (Denton *et al.* 2014). An analysis of surface soils from within the natural wetland area of the park (Fig. 1) yielded values ranging from 137-166 ng/g in the central region, and 116-176 along the south eastern perimeter of the property. According to Fergusson (1990), soils containing mercury concentrations above 100 ng/g dry weight are considered to be significantly contaminated.

The cumulative effect of the above mercury sources on the edible quality of fish that forage among the seagrass beds within the embayment is currently unknown. The primary objectives of the current study were, therefore, to: a) identify and delineate hitherto unknown mercury distribution patterns in the surface sediments from within the shallow embayment; b) determine the collective impact these environmental levels on the edible quality of popular table fish harvested from the area; c) evaluate potential health risks (if any) associated with unrestricted consumption of these fish and, if necessary, make recommendations to extend the survey at some later date to include other fisheries resources within these waters; d) provide additional data that will assist with the identification and delineation of areas of contaminant enrichment within Saipan Lagoon, and e) enhance ongoing marine water quality monitoring and sustainable management activities, and the formulation and development of pollution mitigation strategies for Saipan's coastal waters.

Methodology:

Intertidal sediments taken throughout the study area were composed largely of bioclastic carbonates derived from degraded corals, coralline algae, mollusk shells and foraminifera. Subtidal deposits were dominated by poorly sorted muddy sand, shell gravel and calcareous algal remnants. Inter-site grain size disparities were often appreciable reflecting energetic and circulatory differences between the water masses bathing these shores. Samples taken for analysis were scooped up in hand-held, pre-cleaned polypropylene vials and deep frozen within three hours of collection. In the laboratory the thawed samples were dried to constant weight at

40°C and disaggregated by gently kneading between finger and thumb in clean Ziploc bags. Only the fraction that passed through a 1-mm Teflon screen was taken for analysis.

Fish sampling focused on the emperor fish, *Lethrinus harak*. This species is one of the most commonly encountered emperor fish in Saipan Lagoon (Taylor and McIlwain 2010) and is a popular table fish among local residents. It also has a restricted foraging range, which makes it ideal for monitoring spatial differences in mercury abundance over relatively short distances. All representatives were caught by hook and line at night while foraging among nearshore seagrass beds. Captured individuals were placed on ice as soon as possible and transported to the laboratory in insulated containers. Mercury levels were determined in axial muscle taken immediately below the dorsal fin of each fish. All muscle samples were wet digested in a 2:1 nitric-sulfuric acid mixture at 100°C for 3 hours. Analysis was accomplished by cold vapor Atomic Absorption Spectroscopy using the 'syringe technique' described by Stainton (1971). Calibration standards (5-20 ng/l) were made up in 10% nitric acid containing 0.05% potassium dichromate as a preservative (Feldman 1974). Approximately 10% of all samples were run in duplicate and were accompanied by appropriate method blanks and matrix spikes. Accuracy and precision estimates were based on mercury recoveries from certified standard reference materials and were within acceptable limits.

Principal Findings and Significance:

Funding delays of several months compromised the initiation of this study. As a consequence, the bulk of the sediment sampling was postponed and has only recently been revisited. Hence this report only focuses on the fish analysis, the results of which are presented in Figure 2 below.

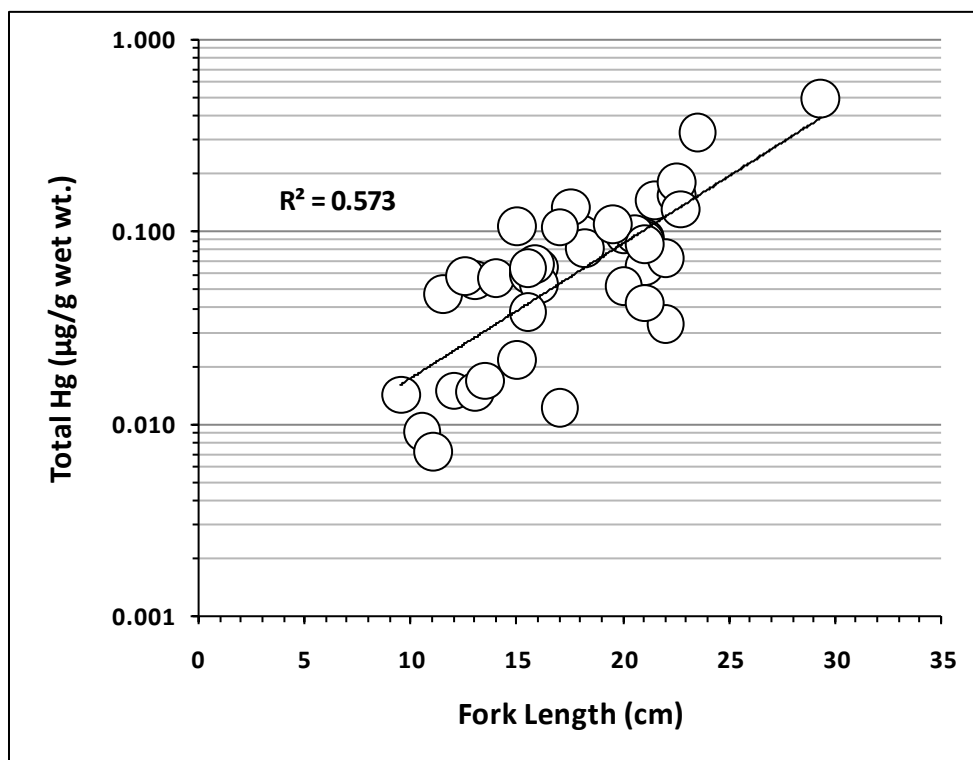


Figure 2: Mercury levels in axial muscle of *Lethrinus harak* from within the study area

WERI has amassed a considerable mercury database for *Lethrinus harak* from clean and relatively polluted environments in Saipan Lagoon (Denton *et al.* 2010). Representatives from relatively clean waters in the northern half of the lagoon typically yield around 0.05 µg/g wet weight, after log transformation of the raw datasets and normalization to a standard fish length of 20 cm. Further south, the equivalent clean-water benchmark is about 20% lower (Denton *et al.* 2018b). Mercury levels in marine teleosts normally range between 0.001 and 0.100 µg/g wet weight depending upon age and trophic level (Holden 1973). During the present study, all fish up to and including 20-cm fork lengths yielded mercury values below this upper limit. In contrast, more than half of those longer than 20 cm exceeded it. The highest mercury value recorded was 0.493 µg/g wet weight and in a 29.3 cm specimen.

Based on the current datasets, 20-cm fish was estimated to contain 0.087 µg/g of mercury on a wet weight basis (95% confidence limits: 0.069-0.109 µg/g wet weight). This is encouraging news for Saipan residents, many of whom regularly fish these waters for subsistence purposes. Nevertheless, a cautionary note is warranted for consumers of fish above a 20-cm fork length. According to USEPA's fish consumption guidelines for the general population, fish with methylmercury concentrations in their muscle tissue of less than 0.088 µg/g wet weight may be eaten on an unrestricted basis (USEPA 2000). In contrast, 8-oz fish meals containing the same concentration as the 29.3 cm specimen noted above, should not be consumed more than once a week; and not more than once a month for women of childbearing age, nursing mothers or sensitive individuals. Mercury in fish occurs predominantly in the highly toxic methylated form and typically accounts for 80-90% of total mercury in axial muscle tissue (Storelli 2005).

In conclusion, fish from within the study area show mild to moderate mercury enrichment and specimens exceeding 20-cm fork length should not be consumed on an unrestricted basis. Given the location of the study area and its relatively close proximity to a number of possible mercury sources, the results seem hardly surprising, and, if anything, are better than expected. Source delineation will be better positioned once the sediment investigative portion of this project has been completed.

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Determination of Rainfall Erosivity Factors for Selected Islands in the Commonwealth of the Northern Mariana Islands (CNMI) Accounting for Climate Variability

Basic Information

Title:	Determination of Rainfall Erosivity Factors for Selected Islands in the Commonwealth of the Northern Mariana Islands (CNMI) Accounting for Climate Variability
Project Number:	2017GU318B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Non Point Pollution, Hydrology, Management and Planning
Descriptors:	None
Principal Investigators:	Mark Lander, Shahram Khosrowpanah

Publication

1. Lander, Mark; Shahram, Khosrowpanah, 2017, "Effect of Climate Variability on Soil Erosion, Land Slide" . Asian Pacific Academy of Sciences, Education, Environmental Management. Abstract, Saipan, November 10, 2017.

PROJECT SYNOPSIS REPORT

Project Title: Determination of Rainfall Erosivity Factors for Selected Islands in the Commonwealth of the Northern Mariana Islands

Problem and Research Objectives:

Soil erosion and sedimentation are major sources of non-point pollution. Sediment is known to damage the reefs, degrade surface water quality, and reduce the productivity of soil. These problems are particularly serious in the humid tropics because tropical islands exhibit substantial rainfall, high rainfall variability, variable topography, and infertile and highly weathered soils. Reducing soil erosion requires having a better understanding of the agents that contribute to the soil erosion such as the impact of rainfall intensity, volume, and duration. The objective of this study is to develop Universal Soil Loss Equation (USLE) average annual rainfall erosivity factor (R factor) values for the islands of the CNMI. One of the major benefits of this project is to enable various agencies dealing with soil erosion and non-point sources of pollution to identify areas of potentially high erosion. These areas can then be targeted for application of soil erosion control practices. The need for developing R factor for the Commonwealth of Northern Marianas Islands (CNMI) brought up by NRCS during the Saipan advisory meeting of September 2016.

The soil erosion process has been extensively studied for many years, but most quantitative information gathered has resulted from research in subtropical and temperate areas. Attempts to extrapolate this information for use in the tropics are seldom satisfactory. For example the study, conducted by Dr. Keith R. Cooley of U.S. Department of Agriculture Research Service (1990), was to determine the R-factors for 10 Pacific Basin islands. Figure 1 provides the results of his study. For his analysis, he used an adjustment factor developed from 30-minute rainfall data from several Hawaii stations to determine the R-factors for the Pacific Basin Islands. Using the adjustment factor, he converted Storm EI₃₀ values computed from hourly rainfall to approximate Storm EI₃₀ values that would have been obtained if 30-minute data rainfall data had been available. This method was used because he lacked sufficient 30-minute rainfall data for these islands.

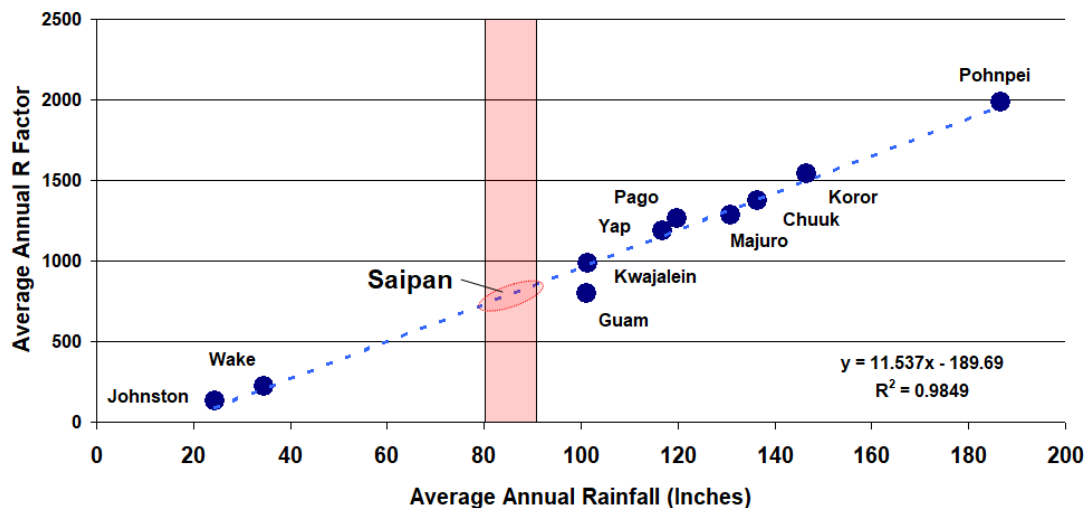


Figure 1. Cooley R-factors of 10 Pacific Basin Islands. An estimate of the Saipan R factor is shown by the light-red band that straddles the range of Saipan rainfall along a regression line through Cooley's data.

The study completed by Khosrowpanah and Dumaliang (1998) indicates that the erosion rates predicted by Cooley could be as much as 45 % in error when using the extrapolated data compared to erosion rates based on actual local climatic conditions. In addition to the obvious lack of knowledge and information concerning the basic parameters governing erosion, the predictive capabilities for soil losses are further limited by the large variability of climate, soils, and topography in tropical regions.

The Universal Soil Loss Equation (USLE) and its updated revision, the Revised Universal Soil Loss Equation (RUSLE) are the equations used most commonly to predict soil erosion rates and soil losses in the tropical pacific. The five major factors used in USLE and RUSLE to predict soil erosion rates are: 1) climate, largely rainfall, 2) soil, its inherent resistance to slaking, dispersion and its water intake and transmission rates, 3) topography, particularly steepness and length of slope, 4) plant cover, and 5) practice factor. Of these, the plant cover, practice and topographic factors are considered management parameters. In contrast, the climate factors and the soil characteristics are normally beyond manipulation by man. In tropical environments, climate or specifically the volume and intensity of rainfall are most significant causes of high soil erosion rates (Foster et al., 1982). This factor is identified in the USLE and RUSLE as the R or rainfall erosivity factor. It is important to characterize the spatial and seasonal variability of this R factor if successful erosion control plans are to be implemented.

The USLE is the most commonly used estimator of soil loss caused by overland erosion. The equation was based on an extensive set of more than 10,000 plot years of runoff and soil loss data from experimental centers in the eastern U.S.A. It was developed to predict average annual soil loss from sheet and rill erosion, not gully or other forms of erosion. The USLE may properly be used to (Wischmeier 1978):

1. Predict average annual soil movement from a given field slope under specified land use and management conditions.
2. Guide the selection of conservation practices for specific sites.
3. Estimate the reduction in soil loss that would result from a change in cropping or conservation practices.
4. Determine how conservation practices may be applied or altered to allow more intensive cultivation.
5. Estimate soil losses from land use areas other than agricultural purposes.
6. Provide soil loss estimation for determining conservation needs.

The USLE, derived empirically is (Lal, 1994):

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where A is the average annual soil loss (tons/acre-year), R is the rainfall factor (ft-ton-in/acre-hour), K is the soil erodibility factor (tons/acre-year / ft-ton-in/acre-hour), LS is the slope-length (dimensionless) and slope-gradient factor (dimensionless), C is the cropping-management factor (dimensionless), and P is the erosion-control practice factor (dimensionless).

The numerical value used for the R-factor in the soil loss equation must quantify the raindrop impact effect and must also provide relative information on the amount and rate of runoff likely

to be associated with the rainfall regimes (Lal, 1994). The storm erosion index or Storm EI₃₀ derived by Wischmeier appears to meet these requirements better than any other of the many rainfall parameters. The relationship is expressed by the equation (Lal, 1994),

$$\text{Storm EI}_{30} = \left\{ \sum 1099 \times [1 - 0.72 \times \text{Exp}(-1.27 \times I_r)] \times R_r \right\} \times I_{30} \quad (2)$$

Where I_r is the rainfall intensity (inch/hour) in a particular time interval of the storm, R_r is the rainfall amount (inch) during the same time interval. These values are input into the equation shown above for each time interval of the storm. The sum of the computed values is called the storm energy or E value. The E value is multiplied by the I_{30} , which is the maximum 30-minute intensity during the storm. The product is called the Storm EI₃₀. It is expressed in hundreds of foot-ton inches per acre-hour (Lal, 1994).

Previous research has indicated that storm soil losses from cultivated fields were directly proportional to a rainstorm parameter identified as the Storm EI₃₀. The sum of the storm EI₃₀ values for a given period is a numerical measure of the erosive potential of the rainfall within the period. The average annual total of the storm EI₃₀ values in a particular locality was the rainfall erosion index (R-factor) for that locality (Lal, 1994).

Methodology:

The first phase of our Saipan project was to acquire all the relevant rainfall data .

The WERI research team made several trip to Saipan to coordinate data collection and project direction with Saipan water resource partners: Robbie Greene (NOAA CZM, Derek Chambers (Saipan BECQ) and Travis Speith (Saipan CUC Chief Operations Officer). Upon acquisition of the data, the team worked to tabulate it in a continuous hourly time series that could be input into a spread-sheet R-factor scheme. The data was somewhat messy, and to fill-in missing blocks, the known monthly value of rainfall from the Saipan International Airport was used to select a complete block or month of data with a similar total at some other location in the Fischer-Porter record to paste into the missing segments. In addition: two complete records of the 1-minute rainfall for two typhoons (Figs. 2 and 3) were artificially stitched into the record.

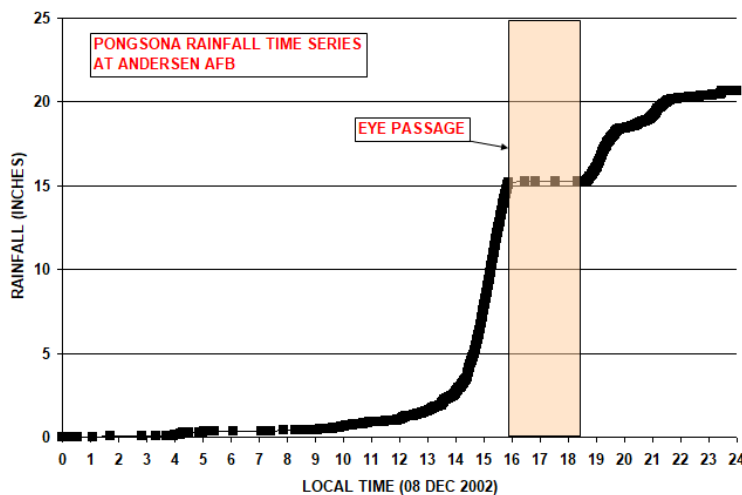


Figure 2. Cumulative rainfall at Andersen Air Force Base during Typhoon Pongsona. Note the light rainfall inside the eye.

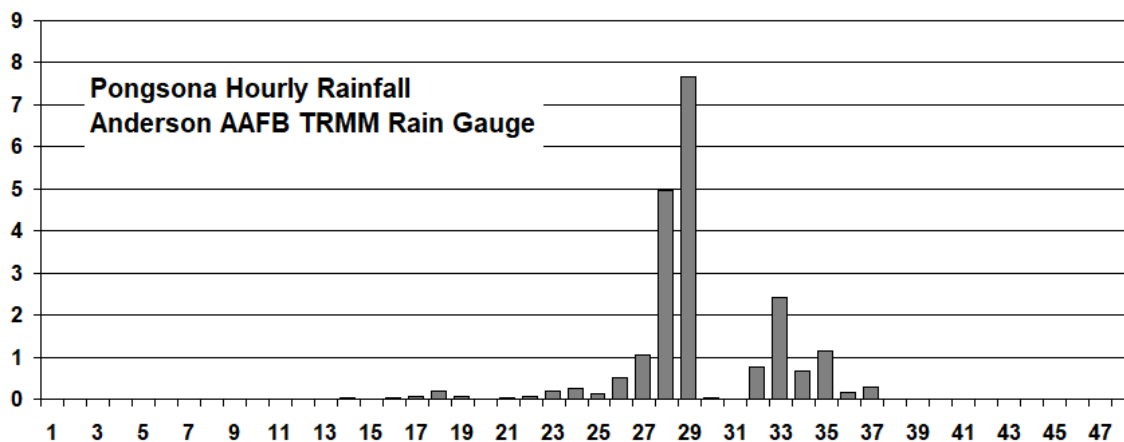


Figure 3. Hourly rainfall during Typhoon Pongsona.

A time series of Fischer-Porter hourly rainfall data was acquired from the Weather Forecast Office (WFO) Guam (contact: Mr. Charles P. Guard, Warning Coordination Meteorologist). This record contains hourly data from 1979 through 2002 (Figure 3, above, is a sample). Some of the data was missing, usually in blocks of a week or so, to a few months. In all, 13.25% of the data was missing. Additional rainfall data was obtained from USGS-sponsored WERI rain gauges, and updated Fischer-Porter data from the Saipan Emergency Management Office where the Fischer-Porter rain gauge is located.

In general, very heavy rainfall in typhoons is missing from all rainfall records, particularly rainfall at short time intervals (e.g., 1-hour). It has been noted on Guam, that nearly all landslide scarring occurs during the heavy rains of typhoons. Sediment plumes extending a mile or more offshore have been noted after typhoon events. Our project made use of special rainfall data sets that were collected during typhoons. WERI rain gauges have survived and monitored rainfall in Typhoon Chataan (Guam 2002), Typhoon Pongsona (Guam 2002) and Typhoon Chaba (Rota 2004). The WERI rainfall data is very precise and is tabulated at 1.5-second intervals, so that one-minute rainfall rates are possible.

WERI Saipan Project Phase 2 (March 2018-February 2019)

Phase 2 of the WERI Saipan R-factor project will be to enter all the rainfall data into an R-factor computing spreadsheet program. Sensitivity to the input of typhoon rainfall will be examined. The R-factor routine will also be used on Guam data (and possibly other locations) as a control. The obtained Saipan R factor will be compared with the original Cooley values, the K-H 2001 values. The Saipan R factor will be placed in the context of the Cooley regression (Fig. 1). The findings will be presented in a capstone workshop, either during the time of the next Saipan Water Advisory Council meeting, the next Saipan APASEEM meeting, or both.

All the information gathered will form the backbone of informative seminars regarding rainfall, erosion, R-factor and the impact of typhoons. The final set of outreach products and the project

WERI technical report will be in final-draft form by the end of the project period (February 2019).

Principal Findings and Significance:

At this time there are no final findings. The data has been collected as part of Phase 1 of the project, and now is to be organized so as to place it into a WERI-designed R-factor spreadsheet calculator. The data collection is not trivial, and in addition to the missing data, there are places in the record where the hourly data for a certain day was entered only as a grand total on the daily sum line, with the comprising hours not tabulated. The rainfall metadata, and WERI project team modifications to the data will form a section in the final technical report. We may also look at the impact that higher rainfall concentrations (i.e., heavier short-term values that sum to the same daily total) make to the R-factor. This is a suggested climate change impact: about the same amount of overall rain, but concentrated into heavier short-term amounts. We hope to look at possible ranges of the R-factor (error bars of a sort) based on factors such as typhoons, and the statistical incorporation of missing data. Lastly, we hope to obtain an R factor for use in CNMI erosion calculations and the design of iso-erodent maps.

Information Transfer Program Introduction

WERI's information transfer program helps to get the results of its applied research on local water resources problems and issues the people whom the research is meant to benefit. Disseminating research results and insights to our local and regional communities is a top priority for WERI researchers. Our principal audiences include engineers and managers in the local water utilities and the engineering and environmental consulting firms that support them; environmental managers and regulators in local and federal agencies, including local military installations; local legislators and other policy makers; and increasingly, local secondary and primary school teachers. Institute technical reports remain a primary vehicle for transmitting information to our target audiences, many of whom are remotely situated and do not have ready access to the broader scientific literature, or require greater detail than is normally found in a standard journal publication. WERI technical reports are also published on the WERI website (www.weriguam.org) from which they can be downloaded. WERI faculty also continue to be major and effective participants in water-related law and policy making on Guam by serving as committee members and chairs on inter-agency advisory boards and by giving invited testimony at legislative oversight hearings.

Every WERI faculty member is afforded an opportunity to contribute to at least one national or international professional meeting, conference, or workshop each year in North America, Asia, or Europe. WERI faculty also conduct annual workshops, courses, and seminars for the professional community. Through teacher training workshops, WERI remains committed to teaching and training tomorrow's water resources professionals. Educating students and teachers on the importance fresh water resource management and conservation remains one of the institute's high priorities. Our annual advisory council meetings in Guam, the CNMI, and the FSM bring together people who typically have little to no contact with one another during the rest of the year. These meetings have become important annual local conferences for information exchange and discussion on common issues, problems and needs in the water resources arena. Finally, we continue to improve the WERI website, which has become our primary link to the professional and educational communities, both at home and abroad, and is now accessible to the great majority of our stakeholders throughout the region, including even some of the more remote islands.

Annual trend reporting, and maintenance and development of the GHS/WERI water resources database

Basic Information

Title:	Annual trend reporting, and maintenance and development of the GHS/WERI water resources database
Project Number:	2017GU311B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Categories:	Management and Planning, Hydrology, Groundwater
Descriptors:	None
Principal Investigators:	Nathan C Habana, John W. Jenson

Publications

1. Miller, Erin, Nathan Habana, Mark Lander, John Jenson, 2017, Chloride and Production Trends, in Abstracts and Program University of Guam Conference on Island Sustainability, University of Guam, Tumon, Guam 10 p.
2. Miller, Erin, Nathan Habana, Mark Lander, John Jenson, 2017, Chloride and Production Trends, WERI Guam Annual Advisory Council Meeting, Water and Environmental Research Institute, University of Guam, Tumon, Guam.
3. Miller, Erin, Nathan Habana, Mark Lander, John Jenson, 2017, Chloride and Production Trends, Guam Hydrologic Survey Workshop, Mangilao, Guam.

PROJECT SYNOPSIS REPORT

Project Title: Annual trend reporting, and maintenance and development of the GHS/WERI database

Problem and Research Objectives

Guam Public Law 24-247 (the Guam Hydrological Survey mandate) requires that WERI:

1. Compile hydrologic data for Guam and maintain an accessible, up-to-date database;
2. Establish agency contacts to maintain a permanent flow of new data to the database;
3. Conduct analyses and publish annual reports on water use, trends and key concerns for use by the governor, legislature, public agencies and private businesses, and citizens.

Consistent with this mandate, the most recent annual meeting of WERI's Guam Advisory Council, on 10 November 2016, identified several critical needs in water resources research, education, and training that call for new updates and additional development of the database. As recognized by the Advisory Council, an up-to-date database of basic information is essential for effective research, education, and decision making for sustainable management of Guam's water resources. There is thus a recognized ongoing need to maintain, update, and improve the database to provide researchers, managers, and professionals in Guam's public and private sectors with reliable, baseline, historical, and current data on Guam's water resources. This year's update and expansion of the database will support each of the specific needs identified above, as well as separate related research and educational projects. There is also an increasingly urgent need to begin delivering annual trend reports, as the region heads into an epic El Nino event and progress continues toward the planned military buildup.

Objectives: This is an ongoing project, with the objectives of meeting standard basic research and educational needs, particularly those identified by WERI's Guam Advisory Council meetings and Groundwater Research Development Group, thus providing basic and essential support for all statistical, geospatial, and modeling studies of Guam's water resources. It is complementary to the National Water Resources Database maintained by the USGS, which contains the data collected from all stations serviced by the USGS, including the rain and stream gages, and groundwater observation wells maintained on Guam under the Comprehensive Water Monitoring Program (Public Law 24-161).

Methodology

The work was done in WERI's existing hydrology and research assistant computing laboratory in the WERI main building. Computing resources utilized the Guam Hydrologic Survey website to include pertinent hydrologic literature library, organized collection of raw data, data analysis and interpretation, sustainable management annual reports, links to development group and supporting websites, in an online access (www.guamhydrologicsurvey.com) to the Northern Guam Lens Aquifer Database as described in WERI Technical Report #141. Student research assistants performed data

entry and processing under the supervision of the WERI GHS Research Associate and principal investigator.

Principal Findings and Significance

The Yigo-Tumon Aquifer Basin (Y-TAB) produces half of the 42 MGD of the 6 total aquifer basins in the Northern Guam Lens Aquifer. WERI receives Guam Waterworks Authority production and chloride data through a cooperation agreement and the Guam Hydrologic Survey. The data was organized and statistics and analytic methods were applied to determine chloride and production response and trends to communicative data. The investigation is ongoing to determine if wells are isolated or communicative with recharge and climate events, and responding to the set pump rates. This study is significant to determining the limits of the aquifer, for which chloride limits pump rate. On the database, the Guam Hydrologic Survey online is taking form, providing the interface for GHS database access. It now makes available worldwide via internet the following:

- The Guam Hydrologic Survey Mission and Management Organization Diagram
- GHS annual reports
- Outreach activity announcement
- Interagency cooperation
- Hydrologic PDF Library and WERI Technical Reports
- Borehole database
- Chloride and production database
- State of the climate and weather
- Maps and Posters
- Presentations

This website serves as the central organization of Guam Hydrologic information transfer. The website will continue to improve and develop to serve the island and the world about Guam's water resource.

Professional Workshop Series on Guam Groundwater Resources

Basic Information

Title:	Professional Workshop Series on Guam Groundwater Resources
Project Number:	2017GU312B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Categories:	Education, Groundwater, Climatological Processes
Descriptors:	None
Principal Investigators:	Nathan C Habana, John W. Jenson

Publications

1. Habana, Nathan; John Jenson, 2017, Guam Water Kids and Guam Department of Education, Northern Guam Lens Aquifer Tour, April 13, 2017, University of Guam, Mangilao, Guam.
2. Habana, Nathan; John Jenson, 2017, Guam Waterworks Authority and UOG EV-511 Students NGLA Tour, Conference on Island Sustainability, Northern Guam Lens Aquifer Tour, April 21, 2017, University of Guam, Mangilao, Guam.
3. Habana, Nathan; Barry Kim, John Jenson, 2017, Executive Tour: Guam Power and Water Authority, Northern Guam Lens Aquifer Tour, June 6, 2017, University of Guam, Mangilao, Guam.
4. Habana, Nathan; John Jenson, Barry Kim, Mark Lander, Bekah Dougher, Erin Miller, Daniel Superales, and Joseph Rouse, 2017, Guam Hydrologic Survey Workshop, GHS Workshop, September 11 & 18, 2017, WERI, University of Guam, Mangilao, Guam.

PROJECT SYNOPSIS REPORT

Project Title: Workshop Series on Guam Groundwater Resources

Problem and Research Objectives

The military buildup and ongoing economic growth anticipated on Guam over the next decade has raised concerns regarding sustainable management of Guam's groundwater resources. Besides educating policy-makers and agency heads it is also essential that island water resource professionals and educators be equipped with an accurate and up-to-date understanding of the essential characteristics of the island's aquifer and the factors that must be considered to frame and implement sustainable management practices. Professional people, including working-level technical professionals in the water resources industry, university instructors, and school teachers, have extremely limited time to engage in instructional opportunities. This proposal is for development and delivery of a series of short-course workshops to local water resource professionals and educators. It will include single-day intensive instruction in (1) the Northern Guam Lens Aquifer Database and development and use of basement map of northern Guam; and (2) sinkholes and surface drainage of the aquifer, and salinity trends, patterns, and processes in the aquifer. It will also include (3) a field trip and 3-D virtual tour of the aquifer, and (4) an introductory workshop in basic GIS, presented in six 2-hour sessions, for student researchers, faculty, and professionals working on groundwater and related problems. Instruction and media organization will be supported by the Guam Hydrologic Survey website containing the instructional materials plus additional references and links to other relevant and useful resources, and forums for maintaining continuing educational interaction and information-sharing. A new GHS website is in development to accommodate the course resources such as the NGLA database that will be useful for island water developers and managers.

Objectives: The scope and objectives of the work include:

- (1) Preparation of instructional materials, including handouts, maps, and references
- (2) Delivery of short-course, intensive workshops, and tours
- (3) Introduction to a webpage containing not only instructional materials but downloadable references and links to other relevant and useful resources
- (4) Design web based information concerning water resource related trends, analysis, and interpretation for educational and professional use such as sustainable management.

Methodology

Materials for the course were made available via PowerPoint presentations and database in the Guam Hydrologic Survey website (www.guamhydrologicsurvey.com). Each participant received the latest basement topography map, which were covered in the lessons. In addition, a new and permanent Guam Hydrologic Survey web-page is housing the wells and borehole database. New features for the webpage include a pertinent Guam hydrologic library, downloadable raw data, web-pages on sustainable management, groundwater modeling, and analysis and interpretation of data (e.g., Pacific ENSO, aquifer production and quality status report, monitoring and exploratory wells).

Instruction carried professional development credit through the University of Guam's Office of Professional and International Programs (PIP) and offered during early fall to accommodate the schedule of educators.

Principal Findings and Significance

The workshop series is an outreach program for various local agencies, private professionals, educators, executives, and students with interest in water resource education. Two outreach programs were provided: the Northern Guam Lens Aquifer (NGLA) Tours and the Guam Hydrologic Survey workshops. The NGLA Tour has a virtual tour that lets its audience see the freshwater lens in the NGLA in a 3-D model of the aquifer and the field trip explored the real aquifer, discussing major aquifer geologic components at selected stop points. The NGLA tour supported the Guam Water Kids (GWK) and reached out to the Guam Department of Education. It was made available at the Conference on Island Sustainability (CIS) for Guam Waterworks Authority (GWA) staff, UOG EV511 students, with assistance from GCC Professor Jocson who is a former student and staff hydrologist at WERI. Then we reached out with the aquifer tour to the island executives at GWA and Consolidated Commission on Utilities, accompanied by UOG President Underwood. The NGLA Tour dates of 2017 are listed:

- 4/13/2017 GWK DOE
- 4/21/2017 CIS 2017 (GWA, Jocson -GCC Professor, EV511)
- 6/6/2017 NGLA Executive Tour (GWA, CCU, Underwood - UOG President)

The workshop was held for two days (September 11 and 18), covering 16 hydrologic topics of the NGLA (30-45 minutes each), such as the aquifer map, online database, rainfall patterns over the aquifer. The attendants were from the government, military, and private sector. The agencies in attendance are listed:

- Guam Waterworks Authority
- Guam Environmental Protection Agency
- Guam Department of Land Management
- Northern Guam Soil and Water Conservation District
- Hagåtña Restoration & Redevelopment Authority
- Allied Pacific Drilling Inc. | Allied Pacific Environmental Consulting, Inc.
- Brown and Caldwell
- PCR Environmental, Inc.
- NAVFAC

Digital Atlas of Yap – A Geospatial Map and Data Server for Resource Management

Basic Information

Title:	Digital Atlas of Yap – A Geospatial Map and Data Server for Resource Management
Project Number:	2017GU315B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Categories:	Management and Planning, Education, Conservation
Descriptors:	None
Principal Investigators:	Joe Rouse, Danko Taborosi

Publications

1. Taborosi, D. et al. 2018. Digital Atlas of Micronesia. Available at www.islandatlas.org. Island Research & Education Initiative (iREi) and Water and Environmental Research Institute of the Western Pacific (WERI).
2. Taborosi, D. and Rouse, J. 2018. Digital Atlas of Yap. In: Digital Atlas of Micronesia. Available at www.islandatlas.org. Island Research & Education Initiative (iREi) and Water and Environmental Research Institute of the Western Pacific (WERI).

PROJECT SYNOPSIS REPORT

Project Title: **Digital Atlas of Yap – A Geospatial Map and Data Server for Resource Management**

Problem and Research Objectives

The island of Yap is the westernmost high island in the Federated States of Micronesia (FSM) and the capital of Yap State, one of FSM's four federal units. It represents the hub of commercial activity and economic development in Western Caroline Islands and the administrative center for a long chain of outlying atolls stretching to Chuuk State in the Central Carolines. In addition, Yap is a part of the Small Island Developing States (SIDS) whose many low-lying yet densely-populated areas are at pronounced risk of natural disasters and effects of climate change and sea-level rise. Sustainable development and effective management of resources, especially in the context of improving resiliency to the effects of climate change and responding to the risk of natural disasters and ameliorating their effects, requires geospatial information of the physical, environmental, and anthropogenic components of the entire system. Such information must be accurate, up-to-date, mutually compatible, and readily available. Given the difficulties in locating and accessing such data in Micronesia, let alone verifying their quality and actually applying them in decision making, Yap has a great need for a unified, comprehensive, and user-friendly information management system for geospatial data. We propose to create a web-based digital repository and dissemination system for GIS and other geospatial data related to Yap, to include all mappable and significant aspects of its natural and man-made geography.

The project aim and scope is to build the Digital Atlas of Yap so that it can serve as a central data repository and digital hub for all geospatial information relevant to Yap. The fundamental objectives of the project are outlined below, in the form of steps toward completion:

- A. Inventory and acquire existing data.
- B. Ensure proper format, quality, completeness, and compatibility of data.
- C. Ensure metadata standardization and completeness.
- D. Create other needed data.
- E. Build web-based data repository and server.
- F. Launch the product and maintain it.

Methodology

Below is an outline of the key characteristics of the proposed “Digital Atlas of Yap”, each item accompanied with a brief description of methodology and procedures used to achieve it.

- A. Digital accessibility. The data management system and all data that populates the Atlas will be in digital format (irrespective of the original format in which it was collected). That ensures easy storage, updating, and dissemination. The system will be modeled on

- the “Digital Atlas of Pohnpei” and will use the same methodology and technical approach. The Atlas will reside on a high-speed and reliable web server.
- B. Dedicated Internet domain. The “Digital Atlas of Yap” will be accessed via a dedicated domain name. As such, it will be perceived by users as a stand-alone, self-contained, and comprehensive product, as opposed to merely a series of pages on an already existing website. The domain name has been determined and is www.islands.fm.
 - C. Attractive design. Every page in this Atlas will be designed in a consistent fashion, including a fixed layout, attractive color schemes, characteristic fonts, and unvarying appearance. This allows the users to experience it as a well-integrated product whose every page and portion is clearly part of the same “brand”. Every page will be identified by a banner-type graphic that bears the name “Digital Atlas of Yap” and stays fixed at the top of the screen.
 - D. User-friendly interface. User interface will be formatted in an intuitive and convenient way that makes it inherently easy to use and requires virtually no time getting used to – particularly to the users of existing Guam resources residing at www.hydroguam.net.
 - E. Easily updateable. Pages in the “Digital Atlas of Yap” will be created using PHP coding which allows easy updates of hundreds of pages simultaneously. Any change whatsoever to the content of the Atlas will be easily implemented and immediately effective.

Principal Findings and Significance

This project is a stand-alone component of a wider program called "Digital Atlas of Micronesia." This wider program is essentially an umbrella project that provides the overall context and digital infrastructure for the ever-increasing volumes of geospatial data available for different islands. The current project is the third component of the atlas and focuses on the island of Yap. The first two components that were built were focused on the islands of Pohnpei and Kosrae. Currently, the Yap component is not yet operational because some of the fundamental data layers were recently thoroughly changed through LiDAR surveying. We are now in the process of updating all previously extant layers to match up with the new LiDAR data and will soon serve them through the unified digital repository. This repository is already on-line and represents a single user interface that acts as means to organize and disseminate geospatial data about any and all Micronesian islands. During the relatively short time that the repository has been active and available to users, we have seen a huge interest across the region and have logged visits from all islands of Micronesia, as well as from places beyond the immediate region, such as Guam and Hawaii, and even worldwide: Japan, Taiwan, the US, Australia, and Europe. We have also noted that hundreds of geospatial data packages have been downloaded from the site and can monitor the scope and types of resources that are being used. Based on user data and feedback from individual users and agencies, we can confidently conclude that the "Digital Atlas of Micronesia" has already become the single most popular and by far the most comprehensive and effective geospatial data source in the Western Pacific.

WERI Information Transfer Program

Basic Information

Title:	WERI Information Transfer Program
Project Number:	2017GU319B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Categories:	Education, Management and Planning, None
Descriptors:	None
Principal Investigators:	John W. Jenson

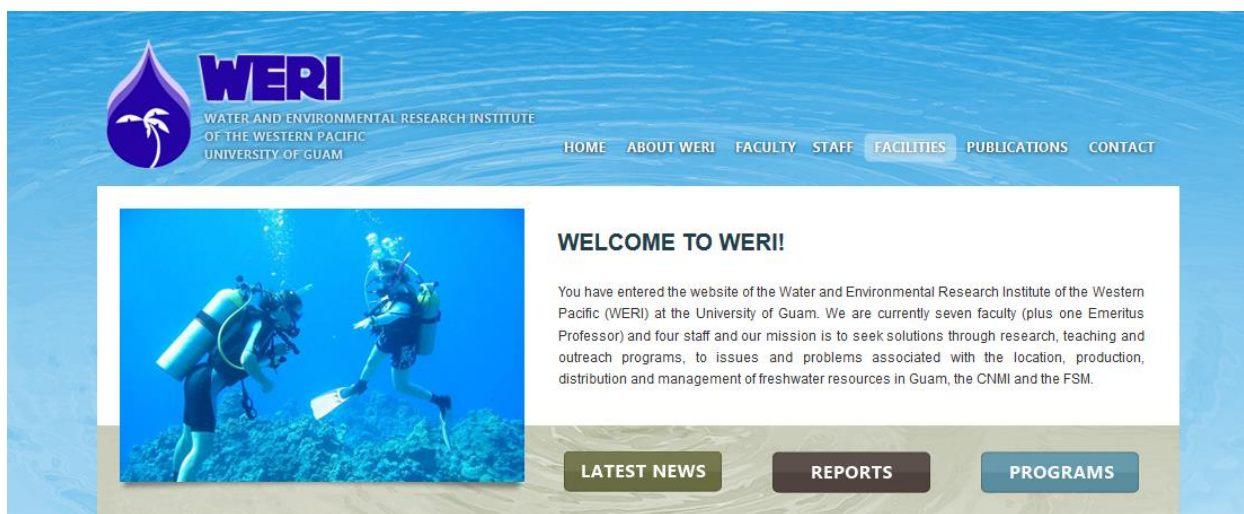
Publications

1. Taborosi, D. et al., 2018, Digital Atlas of Micronesia. Available at www.islandatlas.org. Island Research & Education Initiative (iREi) and Water and Environmental Research Institute of the Western Pacific (WERI).
2. Taborosi, D. and Rouse, J., 2018, Digital Atlas of Yap. In: Digital Atlas of Micronesia. Available at www.islandatlas.org. Island Research & Education Initiative (iREi) and Water and Environmental Research Institute of the Western Pacific (WERI).

PROJECT SYNOPSIS REPORT

WERI recognizes that disseminating our research findings to our community stakeholders and to our colleagues in the scientific and professional communities is the essential final step for effective research. We also recognize that technical information must be communicated not only to a broad audience but also in ways that make it accessible and comprehensible to people in many disciplines, and at educational levels ranging from elementary school students to fellow researchers. Information transfer media include paper brochures and pamphlets as well as web sites, by which we publish or provide access to technical reports, journal articles, and book chapters. We also provide articles and interviews to local news media. The audience for the results of USGS-sponsored research is widely varied geographically and by education level.

The WERI website, funded by this project, is the institute's primary information transfer and dissemination medium. The home page, shown below, is located at <http://www.weriguam.org/>. It features informational links to WERI faculty, staff and Institutional facilities, our current research, education and training activities, primary sponsors and most recent publications. The user-friendly format helps increase visibility of the institute's research programs, particularly for our stakeholders in remote locations where state-of-the-art internet services and computer technology are often lacking.



WERI Website Home Page

This project also funds the design, layout and printing of technical reports resulting from USGS funded research projects. All WERI technical reports are available in downloadable PDF format on the WERI web-site at <http://www.weriguam.org/reports/list>. Selected reports are also published in hard copy, especially for dissemination to users where computer access is limited.

The technical report library is updated as each new report is published. The database search engine process for accessing these reports on line utilizes a composite 'Abstract' database for key word searches. Searches based on 'Author' now search all authors in the author string not just the lead author as before. Upon selection of a particular report, site users are presented with

the complete abstract, which may be viewed prior to downloading the main report. An example is shown below.

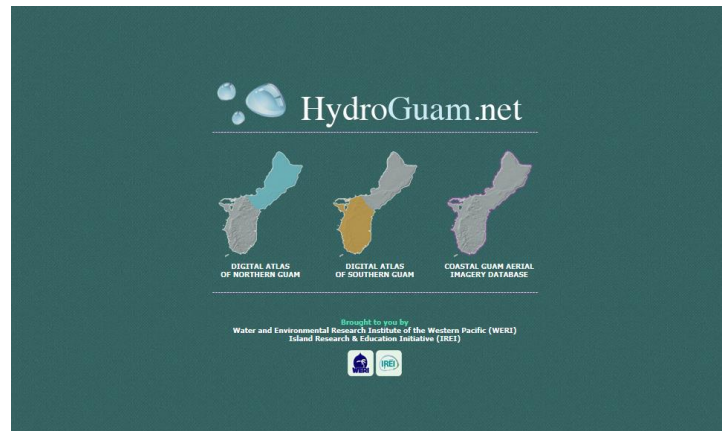


WERI Reports Page

Because of Guam's remote location, and the escalating costs of air travel, it is difficult and costly for researchers to present their findings at technical conferences and symposiums in other parts of the Globe. A portion of the current Information Transfer Project was earmarked for off-island travel expenses for WERI researchers and graduate students presenting refereed professional papers on current or past USGS 104-B projects.

Since 2005, WERI has maintained a unique digital resource for Guam, at www.hydroguam.net. This project began with the *Natural Resources Atlas of Southern Guam*, which was inspired by the need for up-to-date baseline information for sustainable natural resource management and development. Its purpose was to provide a comprehensive library of natural resources information for the fourteen southern Guam watersheds and make that information instantly available to users. The atlas proved to be a highly effective data dissemination hub, as well as a much-used educational tool. At its core lay a wide range of Geographical Information System (GIS) data for southern Guam, providing valuable support for resource management and research, including hydrologic modeling, pollution prevention, soil conservation, and coastal zone management. The tool became very popular in Guam thanks to its simple and user-friendly data dissemination approach: all geospatial data are stored and formatted in such a way that the full content is freely accessible on the Internet via www.hydroguam.net address. Within a relatively short time, the *Natural Resources Atlas of Southern Guam* became so successful that in 2012 it inspired a follow-on project, which was to develop a comparable resource for Northern Guam. That work was completed in late 2013. In 2014, the southern Guam was updated to reflect the new additional information. The new product is entitled *Digital Atlas of Northern Guam* and encompasses many of the strengths of the previously created *Natural Resources Atlas of Southern Guam* with a series of significant improvements. The *Digital Atlas of Northern Guam* is freely accessible on the Internet via www.hydroguam.net. The web interface offers a

range of textual, graphical, statistical, and geographic information to any interested user. Beginning in 2015, the digital atlas concept was extended to include the islands of The Federated States of Micronesia. The extension began with the development of a digital atlas of Pohnpei in 2015-2016. In 2016-2017, the project was extended to Yap. The two are now consolidated into the *Digital Atlas of Micronesia*. Work continues on that atlas of Yap, with the intention of eventually incorporating the rest of the island states, Chuuk, and Kosrae.



USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	2	0	0	0	2
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

The International Association of Hydrological Sciences awarded its 2018 Tison Award to Dr. Ryan T. Bailey of Colorado State University for a 2017 paper based on USGS 104-B-funded work at WERI in 2006-2008: Ryan T. Bailey & Saman Tavakoli Kivi (2017) Method for estimating available groundwater volume of small coral islands, *Hydrological Sciences Journal*, 62:14, 2381-2392, DOI:10.1080/02626667.2017.1382703. The IAHS Tison Award, established in 1982, aims to promote excellence in research by young hydrologists. The Award is granted for an outstanding paper published by IAHS in a period of two years previous to the deadline for nominations. (See "The 2018 Tison Award goes to Ryan T. Bailey & Saman Tavakoli Kivi," at <https://iahs.info/About-IAHS/Competition--Events/Tison-Award/Tison-Award-winners/Bailey--Tavakoli-Kivi/>)

In his acceptance speech, Dr. Bailey explained, "People often ask me why researchers in Colorado, USA are performing work on small tropical islands in the Pacific Ocean. Well, the work presented in our paper began during my thesis work at the University of Guam 11 years ago, when my task was two-fold: first, use complex models to assess groundwater supply on small coral islands under droughts conditions and wave overwash events; and second, to develop a simple equation that could be applied in a spreadsheet, that would allow local island water managers to determine a first-order estimate of groundwater availability for their island given factors such as island width and annual rainfall rate....This work would not [have been] possible without the initial support and guidance of my Master's thesis advisor on Guam, Professor John Jenson, and funding agencies along the way, including the United States Geological Survey, the World Bank, and the Secretariat of the Pacific Community Global Climate Change Alliance. I would also like to thank the local chiefs and residents of Ulithi and Pingelap atolls in the Federated States of Micronesia, who allowed me an initial glimpse of water resources on atoll islands during my Master's degree."

Publications from Prior Years

1. 2015GU285B ("Impact of Multiple Mercury Sources on Edible Quality of Fish from American Memorial Park Nearshore Waters, Saipan, CNMI") - Water Resources Research Institute Reports - Denton, Gary R.W., Jennifer O. Cruz, Mallary N.C. Dueñas, Michael J. Gawel, Justin S. Mills, Karl G. Brookins, 2018, Heavy Metal Assessment of Sediments and Selected Biota from American Memorial Park Nearshore Waters, Saipan Commonwealth of the Northern Mariana Islands. Water and Environmental Research Institute (WERI) of the Western Pacific Technical Report, No. 162, 95pp.
2. 2016GU299B ("Identification and Delineation of Land-Based Mercury Sources Impacting Fisheries in the Southern Central Coastal Region of Saipan Lagoon") - Conference Proceedings - Denton, Gary R.W., Jennifer O. Cruz, Michael S. Trianni, Michael C. Tenorio, Ray S. Masga, 2018, Impact of WWII and Stormwater Discharges on the Mercury Status of Fish from Saipan Lagoon, Saipan, CNMI (Abstract), International Workshop on Environmental Management, Science and Engineering (IWEMSI2018), June 16-17, 2018, Xiamen, Fujian, China.
3. 2014GU275B ("Impact of Stormwater Discharges and WWII on the Mercury Status of Fish from the Southern Section of Saipan Lagoon") - Other Publications - Denton, Gary, Jennifer O. Cruz, David Benavente, Michael S. Trianni, Michael C. Tenorio, 2017, Impact of WWII on Mercury Levels in Fish from Saipan Lagoon, Saipan, Commonwealth of the Northern Mariana Islands (Abstract). The 3rd International Conference on Water Resources and Environment (WRE), June 26-28, 2017, Qingdao University International Center for Academic Exchanges, Qingdao, China.
4. 2016GU299B ("Identification and Delineation of Land-Based Mercury Sources Impacting Fisheries in the Southern Central Coastal Region of Saipan Lagoon") - Other Publications - Denton, Gary R.W., Jennifer O. Cruz, Michael S. Trianni, Michael C. Tenorio, Ray S. Masga, 2017, Tracking Mercury Sources in Central Saipan Lagoon, Asia Pacific Academy of Science, Education and Environmental Management (APASEEM) Annual Conference, November 7-9, American Memorial Park Auditorium, Saipan.
5. 2015GU288B ("Impacts of Land Cover Change on Groundwater Quality in Saipan") - Conference Proceedings - Wen, Y. 2017. Impacts of land cover change on groundwater quality in Saipan, CNMI, USA, in the Proceedings of the 3rd International Conference on Water Resource and Environment (WRE 2017), Qingdao, China, June 26-29, 2017, pp17-18.
6. 2017GU310B ("Exploring the natural limits of the Northern Guam Lens Aquifer: Phase 4 – model implementation, determining ultimate yield in basal and parabasal zones") - Other Publications - Habana, Nathan, John Jenson, Stephen Gingerich, 2017, Evaluating Best-Practice Capacities for a Carbonate Island Karst Aquifer: Northern Guam Lens Aquifer, Guam, USA, Karst Hydrology session - NGWA Groundwater Summit, December 4-7, 2017, NGWA, Nashville, Tennessee.
7. 2017GU310B ("Exploring the natural limits of the Northern Guam Lens Aquifer: Phase 4 – model implementation, determining ultimate yield in basal and parabasal zones") - Other Publications - Superales, Daniel, Nathan C. Habana, Barry Kim, John Jenson, Stephen Gingerich, 2017, NGLA Groundwater Model Explorations, Guam Advisory Council Meeting, November 9, 2017, Tumon, Guam.
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